9

The Use of Technology

```
   M = 1
   Mult = 1.025
10 V = (Multi)^M
   IF V ≥ 2 PRINT M: END
   ELSE M = M + 1: GOTO 10
   END
```

Technology has changed many aspects of doing mathematics, and mathematics education must reflect this reality. Further, some of technology's potential to enhance the teaching and learning of mathematics is already realized and appreciated.

However, along with the potential of such a powerful tool for doing good, the possibility also exists for doing immense, perhaps incalculable harm. There was a time during the past two decades when this critical message was not properly heeded. Some educators welcomed technology as the proverbial magic bullet. For example, the *Curriculum and Evaluation Standards for School Mathematics*, published by the National Council of Teachers of Mathematics (NCTM) (1989), states on page 8: "Contrary to the fears of many, the availability of calculators and computers has expanded students' capability of performing calculations. There is no evidence to suggest that the availability of calculators makes students dependent on them for simple calculations."

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Likewise, it has been stated that technology in the classroom can be a positive force for equity because it helps break down barriers to mathematical understanding created by differences in computational proficiency. Some went so far as to recommend that in every grade calculators be issued to students just as textbooks are.

Such trust and optimism notwithstanding, recent anecdotal evidence and large-scale studies offer a more sobering perspective. In the National Research Council's report *Adding It Up: Helping Children Learn Mathematics* (Kilpatrick, Swafford, and Findell 2001, 356), the authors observed that there is very little empirical research on the effectiveness of various uses of calculators. Regarding international comparisons, they commented:

> On TIMSS [Third International Mathematics and Science Study] similar percentages for calculator use were reported by U.S. teachers. In some countries, including some high-achieving countries (such as Japan and Korea) as well as in some low-achieving countries, mathematics teachers rarely had students use calculators. Internationally, there does not appear to be a correlation between calculator use and achievement in mathematics.

After a meta-analysis of 79 research reports to assess the effects of calculator use, Hembree and Dessart (1986) reported a mixed result on the effects of using calculators. While the use of calculators in concert with traditional mathematics instruction may improve the average student's basic skills with paper and pencil at higher grade levels, they wrote that "[s]ustained calculator use in Grade 4 appears to hinder the development of basic skills in average students."

A more recent meta-analysis by Ellington (2003) of research studies conducted during the past 30 years also lends a note of caution. Of the 127 research reports considered in this broad study, only 49 involved testing of students without calculators (a practice consistent with that of California's testing system), and of those, only 15 research reports involved measuring the acquisition of computational skills. Those 15 studies had a cumulative study population of only 886 students, and Ellington reported that together they did not yield statistically significant results. The confidence intervals for effect size included zero (no effect) and possible positive or negative effects. With the exclusion of a single outlier study out of the 15, the remaining 14 studies showed a slight negative effect of calculator use on the acquisition of computational skills, albeit not a statistically significant effect. The effect of calculator use in individual grades could not be determined from the studies, according to Ellington.

In an analysis of students' responses on the long-term trend NAEP test, Loveless (2004) studied computational accuracy on matched items (with and without calculators allowed during testing). He found significant deficits in students' competency when a calculator was not permitted, as shown in the table, "Matched Calculator Items." (The results are for whole-number operations for students aged nine.)

Matched Calculator Items

All Students

Skill cluster	Calculator allowed?	Accuracy (1990)	Accuracy (1999)	Difference 1990–1999
Addition	No	80.0%	78.4%	–1.6%
	Yes	83.2%	87.0%	+3.8%
Subtraction	No	63.4%	59.7%	–3.7%
	Yes	88.3%	89.2%	+0.9%
Multiplication	No	43.9%	42.5%	–1.4%
	Yes	86.8%	87.9%	+1.1%
Division	No	49.1%	48.3%	–0.8%
	Yes	73.3%	77.1%	+3.8%

Reprinted by permission from Loveless 2004, Table 5.

Regarding the differences in the computational accuracy of U.S. students with and without a calculator, Loveless wrote: "These differences are enormous—the difference between signaling mastery and signaling incompetence." He concludes: "These finding[s] suggest that making calculators available on a test of computation skills can make the difference between concluding that students have acquired certain skills—and concluding that they haven't. On each of these items, at least 40% of the nation's nine year olds computed correctly with or without a calculator provided. For most of the remaining students, calculators are the difference in whether they compute correctly or get the calculation wrong." [1]

Debra Paulson, an eighth grade mathematics teacher in El Paso, Texas, and member of the National Assessment Governing Board that oversees the National

[1] Reprinted by permission from Tom Loveless, *Computation Skills, Calculators, and Achievement Gaps: An Analysis of NAEP Items.* Washington, D.C.: The Brookings Institution, 2004, 17. This paper appears on the Web site http://www.brookings.edu/views/papers/20040415loveless.pdf.

Assessment of Educational Progress (NAEP) test, made the following remarks in a press release on the "NAEP 2000 Mathematics Report Card:" [2]

> Now I would like to discuss calculators, a topic of considerable interest to teachers and of controversy among the public. According to the background information NAEP collects from students, there is a substantial difference in the relationship between calculator use and math achievement at grade 4, compared to grades 8 and 12. Generally, at grade 4 using calculators more is linked to lower achievement. At grades 8 and 12, the students who use calculators more tend to do better, and the positive relationship is especially strong at grade 12.
>
> As you know, the National Assessment is a survey; it does not follow the same children from grade to grade. Thus, it can show the correlation of one factor or another to student achievement. But it cannot be used to prove cause and effect.
>
> But I think there may be several reasons for these relationships. An important part of fourth grade is for students to gain fluency in adding, subtracting, multiplying, and dividing whole numbers and also to develop the strategies for estimating answers and judging the reasonableness of their results. It is important for them to learn the algorithms to compute in whole numbers, and to record their computational thinking with pencil and paper. This fosters an understanding of the base-ten number system that a calculator cannot provide. . . .
>
> In 8th and 12th grades, on the other hand, the use of calculators every day was associated with higher scores. Clearly, calculators are necessary for more advanced math, and the use of graphing calculators is expanding, even in eighth grade. I know in my own classroom that using graphing calculators lets students link tables, graphs and equations, and helps them test conjectures. It also is a great way to get them involved and excited about some fundamental concepts of math (Paulson, 2001, 4).

This framework proposes some guidelines on the use of technology in the classroom. The task is made difficult not only by an absence of hard data to help identify whether or when it is appropriate to use technology in mathematics education but also by the phenomenally rapid rate at which technology is advancing. For these reasons the scope of these guidelines will be restricted to what is warranted by the available evidence.

The Use of Calculators

The *Mathematics Content Standards for California Public Schools* was prepared with the belief that there is a body of mathematical knowledge—independent of technology—that every student in kindergarten through grade twelve ought to know and know well. Indeed, technology is not mentioned in the *Mathematics Content Standards* until grade six. More important, the STAR assessment program—carefully formulated to be in line with the standards—*does not allow the use of calculators all through kindergarten to grade eleven,* except for special education students who have this modification written into their individualized education programs.

[2] This press release appears on the Web site http://www.nagb.org/dpaulson.html.

Teachers need to focus on the goal of having their students understand mathematics and develop the ability to use it effectively.

Development of Basic Mathematical Skills

It is important for teachers to stay focused on the goal of having their students understand mathematics and develop the ability to use it effectively. Teachers should realize that understanding basic concepts requires that the students be fluent in the basic computational and procedural skills and that this kind of fluency requires the practice of these skills over an extended period of time (Bahrick and Hall 1991; Cooper and Sweller 1987; Sweller, Mawer, and Ward 1983). The extensive reliance on calculators runs counter to the goal of having students practice using these procedures. More to the point, it is imperative that students in the early grades be given every opportunity to develop a facility with basic arithmetic skills without reliance on calculators. For example, it should not be the case that, in a fifth-grade classroom, the simple addition $\frac{5}{11} + \frac{3}{5}$ can be done only with the help of a calculator. Students are expected to learn to be adept at making mental calculations and estimates. With a strong technical foundation in place, they will be in a good position to acquire the more complex concepts and procedures throughout their school years.

Preparation for the Use of Calculators

It should not be assumed that caution on the use of calculators is incompatible with the explicit endorsement of their use when there is a clear reason for such an endorsement. Once students are ready to use calculators to their advantage, calculators can provide a very useful tool not only for solving problems in various contexts but also for broadening students' mathematical horizons. One of the most striking examples of how calculators can be appropriately used to help solve problems is the seventh grade topic of compound interest. Initially, compound interest should be developed with problems that can be done without calculators, such as finding the total earnings over two or three time periods when the interest is compounded. However, once the general formulas are introduced, calculators become invaluable in answering questions, such as, What is the size of payments on a 20-year, fixed-rate loan of $50,000? or What will be the total amount of interest paid?

Calculators can also be used in many situations to augment one's ability to teach important mathematical concepts. One can now include such problems as factoring 14,478,750 or finding the sum of $\frac{1}{18731} + \frac{11}{2136}$ in a regular sixth- or seventh-grade mathematics course with the expectation that students will recognize that such problems require the use of calculators. From the point of view of learning mathematics, such problems, particularly the first one, are not mere drill. They require a nontrivial use of systematic search procedures, which cannot easily be demonstrated with simpler problems. Another example is for students to seek the formula for the sum of squares of the first n positive integers. They might ask themselves if the desired formula could be a cubic polynomial in n. Calculators can also be invaluable in working with the extraction of difficult roots and in performing some calculations dealing with special functions, such as the exponential, logarithmic, and trigonometric ones.

Students must be facile in the execution of basic arithmetical and mathematical procedures without the use of calculators. As described in Chapter 1, "Guiding Principles and Key Components of an Effective Mathematics Program," basic computational and procedural skills influence employability in the United States (Rivera-Batiz 1992), and the practice of these skills contributes to the students' development of conceptual understanding and to the sophistication of students' problem-solving approaches (Siegler and Stern 1998; Sophian 1997).

The Use of Computers

The role of computers and software in learning and applying mathematics is changing almost as quickly as the technology is advancing. However, it is important to recognize that working at the computer cannot be considered a substitute for teachers' or for students' active individual involvement in a mathematics class or with homework assignments.

To help ensure that computer education is of maximal benefit to students, it is important to distinguish between general computer education and literacy and the applications of computers in the mathematics curriculum.

All students need to learn basic computer skills, and they should become familiar with several computer applications. They must have the ready ability to learn how to use computer applications and how to navigate and make use of the Internet. These skills can be taught starting in the elementary grades. It is extremely important, however, to recognize a good course in computer skills for what it is and not mistake it for a good course in mathematics. In particular, the teaching of computer literacy *should not take time away from, or be confused with, the teaching of the mathematics curriculum,* as described elsewhere in this framework.

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Computers in the Elementary Grades

The large-scale use of computers *in the mathematics curriculum* needs to be viewed with extreme caution in kindergarten through grade five. Some of the risks are detailed more fully in the report by H. Wenglinsky (1998), from the Educational Testing Service, discussed later in this chapter, and in a historical analysis of technology applications in education by Oppenheimer (2003). As noted previously, it is crucial for students in the elementary grades to acquire basic skills in arithmetic so that they can obtain a solid grounding in the concepts involved. These skills and concepts need to be solidly in place before students can take real advantage of computer or calculator applications in mathematics. Therefore, computers should not play a major role in the mathematics curriculum in kindergarten through grade five.

Computers in the Middle Grades

In the middle grades some schools may wish to take advantage of the many computer programs that can augment students' mathematical education. Here the schools and the individual teachers must be cautious, however. There are many excellent programs, rich in graphics and sound, that can help students learn basic concepts, such as fractions, and that can demonstrate graphs and even help with statistical and data analysis. But many programs are not appropriate for use in a mathematics curriculum. Some are more entertaining than educational, and others essentially do the mathematics for the students, thereby depriving them of the chance to learn for themselves.

Schools and teachers must judge carefully in deciding which types of computer programs to use to augment their mathematics curriculum.

For these reasons schools and teachers must judge carefully in deciding which types of computer programs to use to augment their mathematics curriculum. Those computer programs must be chosen with the same care as that used in choosing other types of instructional materials, such as textbooks. The decision-making process should always focus on whether the program augments the students' learning of the curriculum.

Computers in High School

In the higher grades, students' levels of interaction with computers can be more sophisticated. In particular, computer-programming skills are based on the same logical foundations as is mathematics itself and, if possible, courses in mathematical computer programming should be available to students. However, it is not appropriate to discuss the details of such a course here.

Within the mathematics curriculum the writing of simple computer programs to solve problems in mathematics (or science) can be encouraged through extra-credit homework assignments or projects. The advantages of such assignments are as follows:

- The writing of a program to perform a mathematical calculation can help to solidify students' knowledge of the mathematical concepts involved in solving the problem.
- The lack of tolerance for errors in computer programs forces the students to be precise and careful in their work.
- The algorithms that students implement must be correct and correctly expressed in the computer language being used.

All these benefits are important, not only for the students' mathematical development but also in many other areas. As always, caution needs to be emphasized. For example, merely entering data into a prewritten program does not have much educational benefit and can easily be counterproductive.

Computer skills, particularly the programming skills described previously, can give students a real advantage in entering the job market. Thus, serious attention must be given to developing appropriate courses. Merely being familiar with how to use word-processing programs or interactive mathematics programs will not achieve these objectives.

A Large-Scale Study of Computer Use

The first large-scale study of the relationship between computer use and student achievement was done by H. Wenglinsky (1998), under the auspices of the Educational Testing Service. He used data from the 1996 National

Assessment of Educational Progress (NAEP) examinations and the questionnaires filled out by the fourth and eighth grade students taking the examinations, their teachers, and the administrators of the schools involved.

The largest correlation in the study was for eighth graders who used computers for drill. Those students lagged behind the *average student* on the NAEP examinations by an average of 21.2 weeks (out of an average 36-week school year). In contrast, eighth graders who used computers for applications of mathematics showed a gain of the equivalent of 15.1 weeks of instruction in their average scores.

Correlations do not mean that one thing necessarily caused the other. It could well be that using the computer for drill is a symptom, not a cause, of student difficulties. But, in general, the results of this study strongly reinforce the concerns about overdependence on the computer as a teaching aid.

The Use of the Internet

The Internet is another technological advance that offers interesting opportunities for student learning in mathematics. It provides a wealth of information more rapidly than was possible at any other time in human history. One way teachers might take advantage of this technology is to require students to obtain data for statistical analysis from the Net. But at this stage the Internet seems more useful to teachers themselves than to students. A great deal of information on lesson plans and curricula is available through the Internet, as are many opportunities for teachers to exchange information and advice.

Mathematics teachers should exercise caution to ensure that using the Internet promotes student learning and is an efficient use of student time. If the Internet is a feature of a mathematics lesson, its use must be directly related to the goal of the lesson, and the information accessed must be directly related to the mathematical content of the lesson.

Mathematics teachers should exercise caution to ensure that using the Internet promotes student learning and is an efficient use of student time.

The use of technology in and of itself does not ensure improvements in student achievement, nor is its use necessarily better for student achievement than are more traditional methods. Only carefully conducted research studies will determine how, and with what mathematical content, technology will foster student achievement. At this time the research base is insufficient for making any strong recommendations in favor of using computer and calculator technology in kindergarten through grade six classrooms. Consequently, the framework recommends that extreme care be used in adopting any instructional programs based solely on the use of computers or calculators. [3]

[3] This statement does not refer to programs that use electronic technology as an alternative means to deliver instructional material.